The Large-Scale Structure and Environment of HoII

M. Bureau[1], C. Carignan[2]

[1]Sterrewacht Leiden, Postbus 9513, 2300 RA Leiden, Netherlands
[2]Département de Physique and Observatoire du Mont Mégantic, Université de Montréal, C.P. 6128, Succ. "centre-ville", Montréal, Québec, Canada H3C 3J7

Abstract

Neutral hydrogen VLA D-array observations of the dwarf irregular galaxy HoII, a prototype galaxy for studies of shell formation and self-propagating star formation, are presented. The large-scale H I morphology is reminiscent of ram pressure and is unlikely caused by interactions. A case is made for intragroup gas in poor and compact groups similar to the M81 group, to which HoII belongs. Numerous shortcomings of the supernova explosions and stellar winds scenario to create the shells in HoII are highlighted, and it is suggested that ram pressure may be able to reconcile the numerous observations available.

1 Introduction

HoII is a gas-rich dwarf irregular galaxy on the outskirts of the M81 group, at a distance of 3.2 Mpc ($M_{B_T} = -17.0$ mag). It was one of the first galaxies outside of the Local Group where the effects of sequential star formation on the interstellar medium (ISM) were systematically investigated. Puche et al. (1992) presented high-resolution multi-configuration VLA H I observations, revealing a complex pattern of interconnected shells and holes. They argued for a picture where star formation is self-propagating, photoionization, stellar winds, supernova explosions (SNe), and secondary star formation shaping the ISM. While we do not wish here to challenge the general relevance of such scenarios, we will introduce in the next paragraphs numerous problems they face in the particular case of HoII. Some have been pointed out before, but others are highlighted here for the first time or are revealed by our reanalysis of Puche et al. (1992) data.

2 Neutral Hydrogen Distribution of HoII

We have reanalyzed Puche et al. (1992) multi-configuration VLA observations of HoII, keeping only the D-array data. We produced a continuum-subtracted naturally-weighted cube cleaned to a depth of 1σ (2.75 mJy beam^{-1}), which was used to produce moment maps. The total H I map is shown in Figure 1, superposed on an optical image. Undetected before, a large but faint component extends over the entire northwest half of the galaxy, encompassing the H I cloud detected by Puche et al. (1992). The H I on the southeast side of the galaxy is compressed, giving rise to a striking NW-SE asymmetry, and suggesting that HoII may be affected by ram pressure from an intragroup medium (IGM). The H I now reaches over $16'$ ($4R_{25}$), twice the radius reached previously. The velocity field shows a clear differentially rotating disk pattern (with a warp) in the inner 7–$8'$, but the kinematics at larger radii is rather disturbed. The largest shells are clearly visible as peaks in the velocity dispersion. The total H I flux $F_{\rm HI} = 267$ Jy km s^{-1}, corresponding to $6.44 \times 10^8\ M_\odot$.

"Dwarf Galaxies and their Environment"; International Conference in Bad Honnef, Germany, 23-27 January 2001

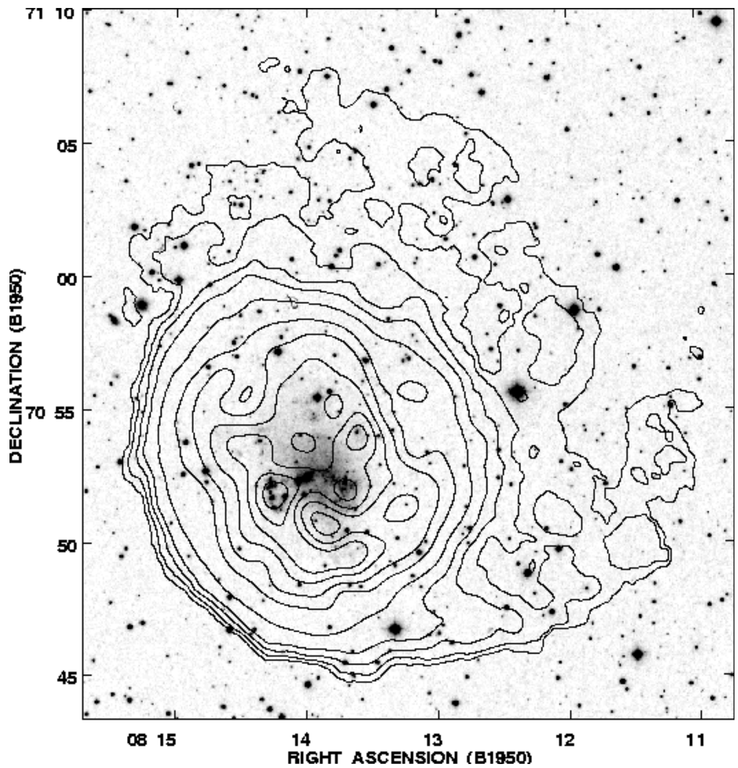

Figure 1: Total H I map of HoII from the VLA D-array data, superposed on a DSS image. Contours are 0.005, 0.015, 0.03, 0.05, 0.10, 0.20, 0.30, 0.45, 0.60, 0.75, and 0.90 times the peak flux of 8.5 Jy beam^{-1} km s^{-1} (2.10×10^{21} atoms cm^{-2} or 16.8 $M_{\odot}$ pc^{-2}). The beam is $66''.7 \times 66''.7$.

3 Environment of HoII

The morphology of the H I in Figure 1 is reminiscent of ram pressure, but it could also be caused by interactions. HoII lies 475 kpc in projection from the center of the M81 group, defined by M81, M82, and NGC 3077. At the group velocity dispersion of 110 km s^{-1} (e.g. Huchra & Geller 1982), it would take HoII a third of a Hubble time to reach the center of the group. However, HoII appears to be part of subsystem of three dwarf irregular galaxies to the northwest of the group's core, along with Kar 52 (M81 Dwarf A) and UGC 4483. If HoII is interacting, it must be with one of these two galaxies. Both Kar 52 and UGC 4483 are much smaller and fainter than HoII and have an irregular optical morphology, but none shows obvious signs of interactions (Bremnes, Binggeli, & Prugniel 1998). In H I, Kar 52 displays a lumpy ring with little rotation, incomplete to the NW (Sargent, Sancisi, & Lo 1983), and UGC 4483 shows a peaked distribution with a faint envelope extended NW-SE (WHISP database). The distance to HoII is identical to that of UGC 4483, but also to that of NGC 2403 and DDO 44 to the SW. This suggests that HoII belongs to the NGC 2403 subgroup, along with Kar 52, UGC 4483, NGC 2365, and DDO 44. Karachentsev et al. (2000) show that the NGC 2403 subgroup is nearer to us by 0.5 Mpc but has a larger radial velocity, suggesting that it is moving towards the M81 group at 110-160 km s^{-1}. Observations of the environment of HoII therefore do not support interactions as a likely mechanism to shape its large-scale structure, and considerations of the M81 and NGC 2403 subgroup as a whole suggest that HoII could have a large velocity relative to a putative IGM. Ram pressure must therefore be considered a serious candidate to explain the H I morphology of HoII. H I observations of the entire region around HoII, Kar 52, and UGC 4483 should help clarify this issue.

4 IGM and X-Rays in Small Groups

The condition for ram pressure stripping can be written as the balance between the pressure exerted by an ambient medium and the restoring force of a galactic disk. The ISM will be stripped if

$$\rho_{\rm IGM} v^2 > 2\pi G \Sigma_{tot} \Sigma_g \tag{1}$$

(Gunn & Gott 1972), where $\rho_{\rm IGM}$ is the IGM density, v the relative velocity of the galaxy with respect to the IGM, and Σ_{tot} and Σ_g the total and ISM surface densities, respectively. Taking $v \approx \sigma \approx 110$ km s^{-1} and Σ_{tot} and Σ_g (corrected for other gaseous species) at the first significantly disturbed contour in Figure 1, we derive a critical density for ram pressure $\rho_{\rm IGM} \gtrsim 2.3 \times 10^{-5}$ atoms cm^{-3}.

A virial mass of 1.13×10^{12} $M_\odot$ is derived from the five most prominent members of the M81 group (Huchra & Geller 1982). Spreading 1% of this mass in a sphere just enclosing HoII, we obtain a mean density of 1.0×10^{-6} atoms cm^{-3}, 25 times too little for stripping. Although it suffers from many shortcomings, this number provides a benchmark with which to compare more sophisticated calculations. The IGM is likely to be more concentrated and clumpy, and the encounter may not be exactly "face-on", but since the group velocity dispersion estimate is based only on a few large galaxies, it is probably an underestimate, and it is in any case unlikely that the group is virialized at the distance of HoII, making its three-dimensional velocity highly unconstrained. If HoII is bound to the M81 group, then the virial mass adopted is severely underestimated. These factors can easily bring the required and derived IGM densities within a factor 2–3 of each other. More convincingly, typical parameters for poor groups are $R_{vir} \sim 0.5h^{-1}$ Mpc and $M_{vir} \sim 0.5 - 1 \times 10^{14} h^{-1}$ $M_\odot$ (Zabludoff & Mulchaey 1998), of which only 10–20% is associated with individual galaxies, leading to a mean density for the remaining matter of $\sim 3 \times 10^{-3}$ atoms cm^{-3} (within the virial radius). If only 1% of this is ordinary interacting baryonic matter, then its density is sufficient to strip galaxies like HoII of their ISM. This is promising, since on scales of the virial radius, the dominant baryonic mass component in groups is the IGM (Mulchaey 2000). In fact, Zabludoff & Mulchaey (1998) report X-ray gas masses of $1 \times 10^{12} h^{-5/2}$ $M_\odot$ for their groups, leading to mean densities for the hot gas of $\sim 7 \times 10^{-5}$ atoms cm^{-3} within the virial radius.

The total X-ray luminosity in groups does not correlate with either the total number of galaxies or the optical luminosity, but it does correlate with the group velocity dispersion and gas temperature. A common fit to cluster and compact group data yields, for $\sigma = 110 \pm 10$ km s^{-1}, $L_X = 10^{39.6\pm1.7}$ erg s^{-1} and $T_{\rm IGM} = 10^{-0.91\pm0.13}$ keV (Ponman et al. 1996). A similar correlation for loose groups alone yields $L_X = 10^{40.5\pm3.6}$ erg s^{-1} and $T_{\rm IGM} = 10^{-0.48\pm0.10}$ keV (Helsdon & Ponman 2000). The large errors on L_X are probably related to the wind injection histories of the groups, which also lead to rather flat surface brightness profiles. There are also indications that the correlations for groups and clusters may be different, so both L_X and $T_{\rm IGM}$ are probably underestimates. There can thus be a substantial amount of hot gas in groups like the M81 group.

Another issue of interest is the survival of any stripped gas in the hot IGM. Following Cowie & McKee (1977), the evaporation timescale for a typical cloud ($n \approx 1$ cm^{-3}, $R \approx 10$ pc) embedded in an IGM at the temperatures mentioned above is 6.2×10^5 to 2.9×10^7 yr. The disturbed ISM in HoII extends over $7 - 8'$ in the radial direction. At a velocity of 110 km s^{-1}, it takes HoII about 6×10^7 yr to cross that distance. Given the strong dependence of the evaporation on the assumed properties of the clouds and IGM, the timescales calculated seem consistent with the observations. It is also possible to show that, in the conditions of interest here, cooling and viscous stripping (Nulsen 1982) are negligible compared to evaporation. At the IGM density required for ram pressure stripping, the cooling timescale is $6.0 \times 10^9 - 5.9 \times 10^{10}$ yrs and the timescale for (complete) viscous stripping of our typical cloud is 5.2×10^9 yr.

5 Creation of Shells and Supershells

Over 50 H I holes were cataloged in HoII by Puche et al. (1992), who obtained estimates of their kinematics ages, previously enclosed H I masses, and creation energies. Many correlations between these quantities are presented, arguing for a formation of the holes through SNe and stellar winds, but many are truly a reflection of the properties of HoII rather than of the formation mechanism of the holes. Also, Hα emission does not preferentially fill small holes or trace the edges of large ones. A similar picture emerges from far-ultraviolet observations (Stewart et al. 2000). Furthermore, the shells are devoid of hot gas, and X-ray emission is not preferentially associated with H II regions or H I holes; only a mixed bag of objects is observed (Kerp & Walter 2001). The SN rate derived from radio continuum observations agrees well with that derived from the H I shells (Tongue & Westpfahl 1995), but the energy is deposited in the central regions of HoII only, hardly helping to explain how the entire web of interconnected shells formed. Furthermore, in most cases where useful limits are derived, stellar clusters expected to remain from massive star formation episodes are simply not seen (Rhode et al. 1999). Multi-wavelength observations thus pose a challenge to SNe and stellar winds scenarios for the formation of the shells in HoII, particularly in the outer parts of the disk where no star formation appears to be taking place.

Other mechanisms exist to explain the formation of the shells and reconcile models with observations (see Rhode et al. 1999). In particular, SN may not be spherically expanding in a uniform ISM, as assumed, and the initial mass function could be very top-heavy. Gamma-ray bursts may also be more efficient at creating holes and shells. All these mechanisms, however, still require massive star formation in the outer parts of the disk. A fractal H I, overpressured H II regions, external ionization sources, and/or high-velocity clouds can bypass this requirement.

Here, we would like to suggest that ram pressure can provide yet another solution to the problem of shell formation in HoII. Ram pressure can create holes in an H I disk where local minima in the surface density exist. Thus, it can provide an efficient mechanism to enlarge pre-existing holes, created by SNe or otherwise, and it can explain the overestimated energy requirements (or lack of observational signature) from SNe and stellar wind scenarios. Obviously, however, shell formation through ram pressure should be properly modeled before making further claims. Ram pressure should be easy to distinguish from internal, pressure-driven events such as SNe and stellar winds, as the shells will have a "bullet-hole" geometry similar to that caused by high-velocity cloud collisions (e.g. Tenorio-Tagle 1980). Of course, in the case of HoII, a direct proof of a sufficiently dense IGM must also be found before any ram pressure model can be taken seriously.

References

Bremnes, T., Binggeli, B., & Prugniel, P. 1998, A&AS 129, 313
Cowie, L. L., McKee, C. F. 1977, ApJ 211, 135
Gunn, J. E., & Gott, J. R. III 1972, ApJ 176, 1
Helsdon, S. F., & Ponman, T. J. 2000, MNRAS 315, 356
Huchra, J. P., & Geller, M. J. 1982, ApJ 257, 423
Karachentsev, I. D., et al. 2000, A&A 363, 117
Kerp, J., & Walter, F. 2001, in *X-ray Astronomy 2000*, eds. R. Giacconi, L. Stella, & S. Serio, in press.
Mulchaey, J. S. 2000, ARA&A 38, 289
Nulsen, P. E. J. 1982, MNRAS 198, 1007
Ponman, T. J., Bourner, P. D. J., Ebeling, H., & Böhringer, H. 1996, MNRAS 283, 690
Puche, D., Westpfahl, D., Brinks, E., & Roy, J.-R. 1992, AJ 103, 1841
Rhode, K. L., Salzer, J. J., Westpfahl, D. J., & Radice, L. A. 1999, AJ 118, 323
Sargent, W. L. W., Sancisi, R., Lo, K. Y. 1983, ApJ 265, 711
Stewart, S. G., et al. 2000, ApJ 529, 201
Tenorio-Tagle, G. 1980, A&A 88, 61
Tongue, T. D., & Westpfahl, D. J. 1995, AJ 109, 2462
Zabludoff, A. I., & Mulchaey, J. S. 1998, ApJ 496, 39